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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

September 24, 1968

Highway Departments of All States,
District of Columbia and Puerto Rico

Attention: Materials Engineers

During the recent Santa Fe AASHO Materials Meeting, considerable interest was shown in California's development work which t[illegible] for the control of materials. At the su[illegible] Materials Resear[illegible]ting, by this l[illegible] project to fur[illegible] progress. Calif.[illegible]s and specif[illegible]

68-59

JOHN L. BEATON
Materials and Research Engineer

Enclosures

[illegible] Ha[illegible] [illegible]d, Washington Office,

[illegible] of Public Roads, I am distribu[illegible]

[illegible] the latest status report on this

[illegible] interested Materials Engineers of our

[illegible] No. 908 and examples of control chart[illegible]

[illegible] al[illegible] enclosed.

Very truly yours,

State of California

Transportation Agency

Memorandum

To : Mr. John L. Beaton
Materials and Research Engineer

Date September 20, 1968

File :

From : **Department of Public Works—Division of Highways**
Materials and Research Department

Subject: Status Report on Research Project "Application of Statistical Quality Control Methods"

A brief outline of important developments of the quality control program is as follows:

1. The new statistical specifications have been formalized with limits based on the results of an earlier random survey of 18 construction projects and the research of others in this field.

2. Methods have been developed which will aid the Resident Engineer in decision making and graphically provide back-up for these decisions. These methods include the moving average concept, which bases the decision to accept or reject material on the average of the five most recent test results, and the use of control charts which provide visual evidence of trends in process control.

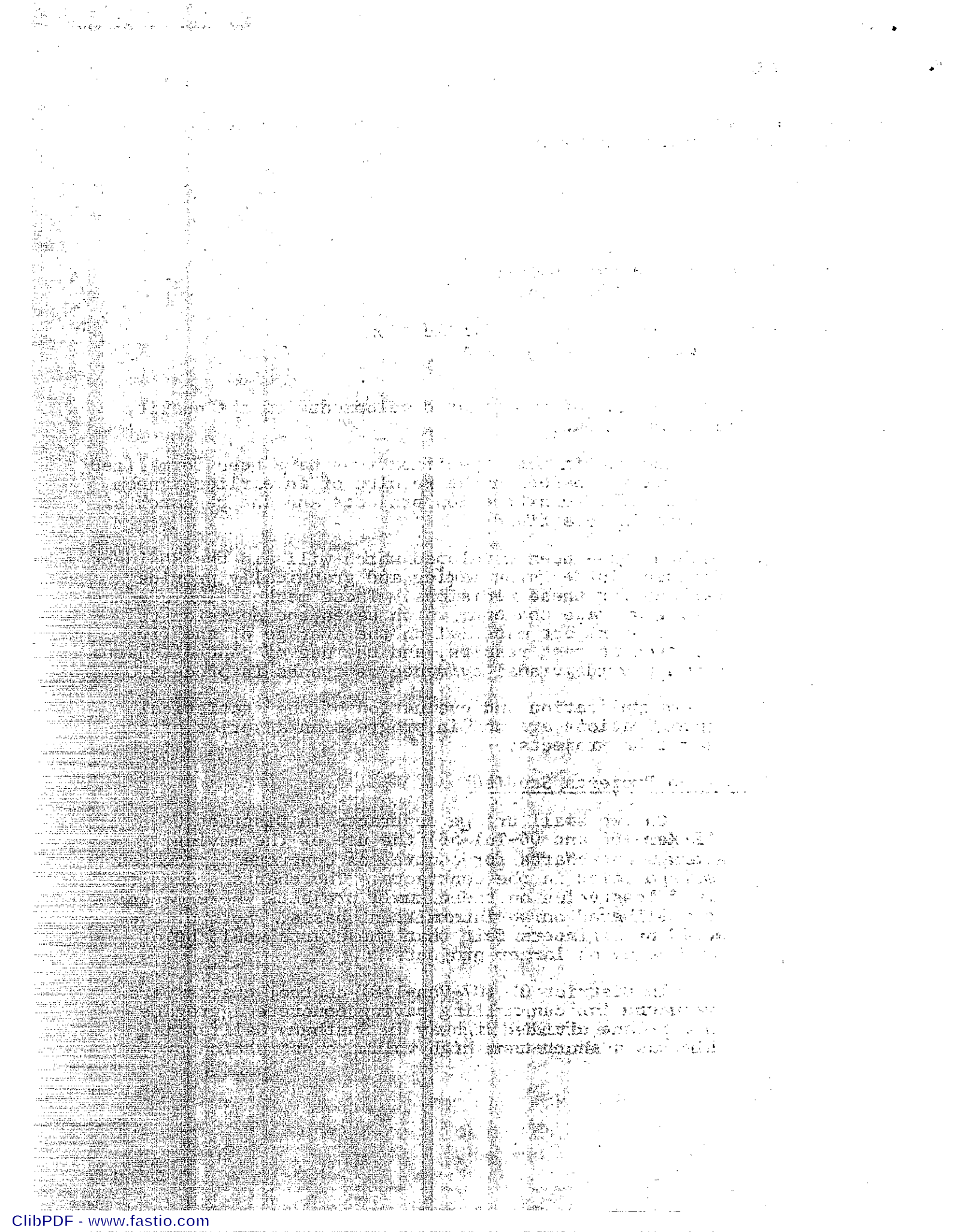
3. Field application and evaluation of the statistical specifications are now in progress on a series of construction projects.

Completed Projects Studied

On two small bridge contracts in District 06 (06-Ker-166 and 06-Tul-65) the use of the moving average and charts for control of concrete aggregates was specified in the contracts. The charts seemed to be of less value on these small projects where material was delivered on an intermittent basis. Both of the Resident Engineers felt that the charts would be of real value on larger projects.

In District 07 (07-Ven-118) control charts were evaluated for controlling paving concrete aggregate on a 6-lane divided highway in Southern California. This was a short-term high volume construction project

FORM H-AD 38 (REV. 8-66)



involving the placement of approximately 4,500 cubic yards of concrete a day for a total of 29,000 yards at completion. The results of this study indicate that the application of these control methods is effective on short-term high production projects.

Project Studies In-Progress

Control charts on concrete aggregate have been kept on the 03-Sac-5 bridge job for over a year. This is a long-term project involving one or two 400 cubic yard pours a week to total 33,000 yards at completion. The data obtained from this job has been instrumental in the development of Calif. Test Method 908.

Job 03-Sac-80 is a widening project which involves the placement of aggregate base and asphalt concrete. Control charts are being kept on a trial basis (not a part of the contract) for this project also.

District 08 (08-SBd-40) and District 05 (05-Mon-1) are using control charts for aggregate in subbase, base, asphalt concrete, and cement treated base. The Resident Engineers have made helpful suggestions for improving the charts and forms.

Future Project Studies

District 07 (07-LA, Ora-91) will utilize control charts on a trial basis for CTB aggregates and percent-of-cement in cement treated base. It is anticipated that these items will be underway in the near future.

The new specifications have been included in the contract for a bridge job (04-SC1-280) in San Jose. About 83,000 cubic yards of structural concrete will be placed in 535 working days. This contract will put the statistical tolerances, moving averages, and control charts to a true test and expose them to critical field evaluation.

4. The value of these statistical methods is receiving attention throughout the State. District 05 has indicated that they would like to set up control charts in aggregate plants throughout the district. Recent experience on the 05-Mon-1 project has demonstrated the importance of a graphic presentation of test results.

[illegible] placement [illegible] approximately [illegible] yd [illegible] of concrete [illegible] total of [illegible] [illegible] of this [illegible] the application [illegible] control [illegible] [illegible] high quality.

[illegible]

[illegible] have been [illegible] bridge [illegible] for [illegible] a year. This [illegible] program [illegible] 03 which [illegible] total 35,000 yd [illegible] of concrete [illegible] this job has [illegible] of [illegible] Test Method [illegible]

[illegible] 03 [illegible] 80 is a widening project which involves [illegible] of aggregate base and asphalt concrete [illegible] charts are being [illegible] basis (not [illegible] contract) for this project also.

District 08 (08-Riv-10) and District 05 (05-Mon-[illegible]) [illegible] control charts for aggregate in subbase, base, asphalt concrete, and cement treated base. The Resident Engineers have made helpful suggestions for improving the [illegible] and forms.

Future Project Locations

District 07 (07-LA-Ora-91) will include control charts on a trial basis for aggregate and [illegible] in cement treated base. It is anticipated that [illegible] will be [illegible] in the near future.

[illegible] new specifications have been included in the contract for a bridge job (04-SCl-280) [illegible] About 15,000 cubic yards of structural concrete will be placed in 235 working days. [illegible] the [illegible] moving averages, and [illegible] control charts as a [illegible] and [illegible] evaluation.

The value of these statistical methods is [illegible] that the State [illegible] that they would like to [illegible] throughout the [illegible]. Reports [illegible] on the 05-Mon-1 project has [illegible] the [illegible] of a graphic presentation of test results.

Headquarters Construction Department has authorized the use of a modified version of Calif. Test Method 908 for the control of compaction of cement treated base on 12 projects.

Recently, over fifteen visits have been made to these projects to explain our research objectives and obtain opinions of field personnel. Field experience on the completed projects has indicated that the application of moving averages and control charts are effective on both long and short-term high production jobs. The field engineers who have used these methods agree that this approach to job control is of value.

George B. Sherman

G. B. Sherman
Asst. Materials and Research Engineer

DTS:sc

SECTION 9-3. CONCRETE

9-3.01 Aggregate.—Whenever both individual sample and moving average requirements are specified in this section, statistical means will be used for determination of specification compliance of concrete aggregate in accordance with Method No. Calif. 908.

Footnote (1) in Section 90-2.02A, "Coarse Aggregate," of the Standard Specifications is superseded by the following:

> No individual sample shall have a cleanness value of less than 73. The moving average shall not be less than 75.

Footnote (2) in Section 90-2.02B, "Fine Aggregate," of the Standard Specifications is superseded by the following:

> No individual sample shall have a sand equivalent less than 73. The moving average shall not be less than 75.

The third and fourth paragraphs in Section 90-3.02B, "Coarse Aggregate—Without Finish Screening," of the Standard Specifications are superseded by the following:

> Before beginning any concrete work, the Contractor shall submit in writing to the Engineer the gradation of the primary aggregate nominal sizes which he proposes to furnish. If a primary coarse aggregate is separated into 2 sizes, the proposed gradation shall consist of the gradation for each individual size, and the proposed proportions of each individual size, combined mathematically to indicate one proposed gradation. Such gradation shall meet the grading requirements shown in the table in said Section 90-3.02B, and shall show the percentage passing each of the specified sieve sizes.
>
> The moving average gradation and the individual sample gradation of the primary aggregate nominal sizes as furnished for the work shall be of such uniformity that the material passing the 2", 1", ¾", and ⅜" sieves will not vary from the gradation submitted of the primary aggregate nominal sizes by more than the following:

	Individual Sample	Moving Average
2½" x 1½" Primary Aggregate Nominal Size:		
Maximum variation of percentage of material passing 2" sieve	±14	±12
1½" x ¾" Primary Aggregate Nominal Size:		
Maximum variation of percentage of material passing 1" sieve	±14	±12
1" x No. 4 Primary Aggregate Nominal Size:		
Maximum variation of percentage of material passing ¾" sieve	±12	±10
Maximum variation of percentage of material passing ⅜" sieve	±12	±10

> The variations shown for the individual samples are the maximum allowable and will be reduced by the amount necessary to meet the grading requirements of the first and second paragraphs in Section 90-3.02B.

The third and fourth paragraphs in Section 90-3.03, "Fine Aggregate Grading," of the Standard Specifications are superseded by the following:

> Before beginning any concrete work, the Contractor shall submit in writing to the Engineer the gradation of the fine aggregate which he proposes to furnish. If fine aggregate is separated into 2 sizes, the proposed

gradation shall consist of the gradation of each individual size, combined mathematically to indicate one proposed gradation. Such gradation shall meet the grading requirements shown in the table in said Section 90-3.03 and shall show the percentage passing each of the specified sieve sizes.

The moving average gradation and the individual sample gradation of the fine aggregate as furnished for the work shall be of such uniformity that the material passing the Nos. 16, 30, and 50 sieves will not vary from the gradation submitted by more than the following:

	Individual Sample	Moving Average
Maximum variation of percentage of material passing No. 16 sieve	±10	±8
Maximum variation of percentage of material passing No. 30 sieve	±9	±7
Maximum variation of percentage of material passing No. 50 sieve	±6	±4

The variations shown for the individual samples are the maximum allowable and will be reduced by the amount necessary to meet the grading requirements of the first paragraph in Section 90-3.03.

The soundness requirement for fine aggregate in Section 90-2.02, "Aggregates," of the Standard Specifications will be waived, provided that the durability index, D_f, of the fine aggregate is 60, or greater, when determined by Test Method No. Calif. 229.

9-3.02 Water.—The first paragraph in Section 90-2.03 of the Standard Specifications is superseded by the following:

In conventionally reinforced concrete work, the water for curing, for washing aggregates, and for mixing shall be free from oil and shall not contain more than 1,000 parts per million of chlorides as Cl, nor more than 1,300 parts per million of sulfates as SO_4. In prestressed concrete work, the water for curing, for washing aggregates, and for mixing shall be free from oil and shall not contain more than 650 parts per million of chlorides as Cl, nor more than 1,300 parts per million of sulfates as SO_4. In no case shall the water contain an amount of impurities that will cause a change in the setting time of portland cement of more than 25 percent nor a reduction in the compressive strength of mortar at 14 days of more than 5 percent when compared to the results obtained with distilled water.

9-3.03 Concrete Mixing.—The minimum required revolutions at the mixing speed for transit-mixed concrete specified in the last paragraph in Section 90-6.04, "Time or Amount of Mixing," of the Standard Specifications, may be reduced to not less than that recommended by the mixer manufacturer, but in no case shall the number of revolutions be less than that required to consistently produce concrete which conforms to the uniformity requirements in Section 90-6.01, "General," of the Standard Specifications. The number of revolutions recommended by the mixer manufacturer shall be indicated on the mixer manufacturer's serial plate attached to the mixer. The Contractor shall furnish test data acceptable to the Engineer verifying that the make and model of the mixer will produce uniform concrete conforming to the provisions in said Section 90-6.01 at the reduced number of revolutions shown on the serial plate.

9-3.04 Portland Cement.—The first and second paragraphs in Section 90-2.01 of the Standard Specifications are superseded by the following:

Portland cement for all concrete construction, except precast prestressed concrete piling and precast prestressed concrete members, will be

MATERIALS AND RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

Method No. Calif. 908-A
March 15, 1968
(2 pages)

STATISTICAL MEANS FOR DETERMINATION OF SPECIFICATION COMPLIANCE USING MOVING AVERAGES AND CONTROL CHARTS

SCOPE

This method describes procedure for using statistical means for determining specification compliance of materials on a construction project.

PROCEDURES

A. Definitions

1. Test Result - An individual result used in determining acceptance of material. In some cases, such as the Ball Penetration Test (Test Method No. Calif. 533), each test result is the average of three or more individual readings. The number of readings may vary with individual test procedures depending upon the accuracy of the test.

2. Moving Average - Unless otherwise specified, the moving average is the average of the four most recent test results representing accepted material plus the test result from the material being considered for acceptance.*

3. Control Chart - A chart for the presentation and analysis of data. In the case of the Moving Average, the data are obtained from more than one test result. Control charts provide visual evidence that a process is in operational control.

B. Initial Determination

1. The moving average at the start of the job is not determined until the second test result is obtained; however, if the material is accepted, the first test result shall be shown as the first point on the control chart. For the first test result, only the specification limits for the individual test shall apply and this test result, if the material is accepted, shall be included with the second test result for calculating the moving average. The moving average for

* These results will be rounded to the same number of significant figures as in the individual test result. When the decimal fraction to be dropped is less than 5, round down; if greater than 5, round up; and if it is a 5, round either up or down to the even number (see Examples Nos. 1 and 2).

the second through the fourth test results is the average of all results representing previously accepted material plus the test result from the material being considered. From the fifth test result on, definition A-2 applies. Any test result representing rejected material is not included in the calculations for the moving average to be plotted on the control charts.

C. Procedure When Individual Results are Out of Specifications

1. Generally, specifications will require both individual tests and moving average results to be within specified limits. At the discretion of the engineer, an individual test result outside the specification limit may be waived providing the moving average is within limits, however such a test result must be included when calculating moving averages. If the moving average exceeds the specified limits, the material does not meet specifications.

2. If the moving average is out of specifications and the contractor has taken significant steps to correct any deficiencies, the next individual sample that meets specifications after production is resumed may, at the discretion of the engineer, be used to start a new moving average series.

D. Noncontinuous Moving Average

1. The moving average for any one material does not necessarily have to be continuous for the complete project. At the discretion of the engineer, a new moving average series may be started when there are periods of inactivity, changes in materials or processing, change in job mix formula, etc.

E. Frequency of Sampling

1. A guide to the frequency and location of sampling is given in the Construction Manual.

REFERENCE

Division of Highways Construction Manual

End of Method No. Calif. 908-A

March 15, 1968

EXAMPLE CALCULATIONS FOR MOVING AVERAGES FOR CONTROL CHARTS

These examples are intended as a guide to the Resident Engineer and are not a part of Method No. Calif. 908.

This guide shows an optional use of a caution zone with the control chart. The caution zone, though not a part of the method, is intended as a warning area on the control chart where prudent forethought should be exercised to minimize risk of going out of specifications. Caution zones are arbitrarily selected and used to indicate when the process appears to be going out of control. No rules or set criteria are given because materials variance throughout the State may cause test results in some areas to approach the limits and still consistently be in specifications. For this reason, the area defined as the caution zone will be set by the engineer.

All tests on material incorporated into the project should be shown on the control chart. Any tests on material rejected and not incorporated into the project should not be shown on the control chart.

Tests on progress samples may, at the discretion of the engineer, be plotted on the control chart as individual test results but are not to be included in the moving averages.

EXAMPLE NO. 1

Calculations to Determine Moving Averages for the Sand Equivalent Test
(See Figure I for a plot of the data)

Assume a specification for individual test of not less than 73 and a moving average not less than 75. The caution zone for this example was arbitrarily set between 75 and 80.

EXAMPLE NO. 1 (continued)

Test No.	Date	Individual Test Result (Min.73)	Sum	Moving Avg.* (Min. 75)	Rounded To
1	8-11-67	79**	---	----	---
2	8-14-67	85	164	÷ 2 = 82.0	82
3	8-16-67	84	248	÷ 3 = 82.7	83
4	8-18-67	72 Waived and accepted by Engr.	320	÷ 4 = 80.0	80
5	8-22-67	80	400	÷ 5 = 80.0	80
6	8-24-67	75	396	÷ 5 = 79.2	79
7	8-25-67	74	385	÷ 5 = 77.0	77
8	8-28-67	68	369	÷ 5 = 74 Material rejected and results not shown on control charts.	

Operation discontinued after Test No. 8 and significant step(s) taken by the contractor to correct deficiency before additional material was accepted.

9	8-29-67	79**	---	----	---
10	8-31-67	80	159	÷ 2 = 79.5	80
11	9-5-67	81	240	÷ 3 80.0	80
12	9-7-67	83	323	÷ 4 80.7	81

* These results will be rounded to the same number of significant figures as in the individual test result. When the decimal fraction to be dropped is less than 5, round down; if greater than 5, round up; and if it is a 5, round either up or down to the even number.

** Show this test result as the first value on the moving average control chart.

EXAMPLE NO. 2

Calculations to Determine Moving Averages for 1-1/2" x 3/4" Concrete Aggregate (Maximum Variation of Percentage of Material Passing 1" Sieve) (See Figure II for a plot of the data)

Contractor's Proposed Average (Job Formula) = 26%
Assume the specifications allow an individual test variation of ± 14% and a moving average variation of ± 12% from the average submitted by the contractor.

The caution zone for this example was arbitrarily set between ± 4% of the lower and upper limits.

Test No.	Date	Individual Test Result (Limits 12% to 40%)	Sum	Moving Avg.* (Limits 14% to 38%)	Rounded To
1	6-5-67	27**	---	----	---
2	6-6-67	24	51	÷ 2 = 25.5	26
3	6-8-67	28	79	÷ 3 = 26.3	26
4	6-12-67	29	108	÷ 4 = 27.0	27
5	6-14-67	35	143	÷ 5 = 28.6	29
6	6-16-67	34	150	÷ 5 = 30.0	30
7	6-20-67	42 Waived and accepted by Engr.	168	÷ 5 = 33.6	34
8	6-22-67	38	178	÷ 5 = 35.6	36
9	6-26-67	40	189	÷ 5 = 37.8	38
10	6-27-67	42	196	÷ 5 = 39 Material rejected and results not shown on the control charts.	

Operation discontinued and significant step(s) taken to correct deficiency before additional material was accepted.

* These results will be rounded to the same number of significant figures as in the individual test result. When the decimal fraction to be dropped is less than 5, round down; if greater than 5, round up; and if it is a 5, round either up or down to the even number.

** Show this test result as the first value on the moving average control chart.

EXAMPLE NO. 2 (continued)

Test No.	Date	Individual Test Result (Limits 12% to 40%)	Sum	Moving Avg.* (Limits 14% to 38%)	Rounded To
11	6-29-67	25**	---	----	---
12	6-30-67	28	53	÷ 2 = 26.5	26
13	7-5-67	20	73	÷ 3 = 24.3	24
14	7-7-67	25	98	÷ 4 = 24.5	24

* These results will be rounded to the same number of significant figures as in the individual test result. When the decimal fraction to be dropped is less than 5, round down; if greater than 5, round up; and if it is a 5, round either up or down to the even number.

** Show this test result as the first value on the moving average control chart.

Figure I

CONTROL CHART OF MOVING AVERAGES FOR
SAND EQUIVALENT

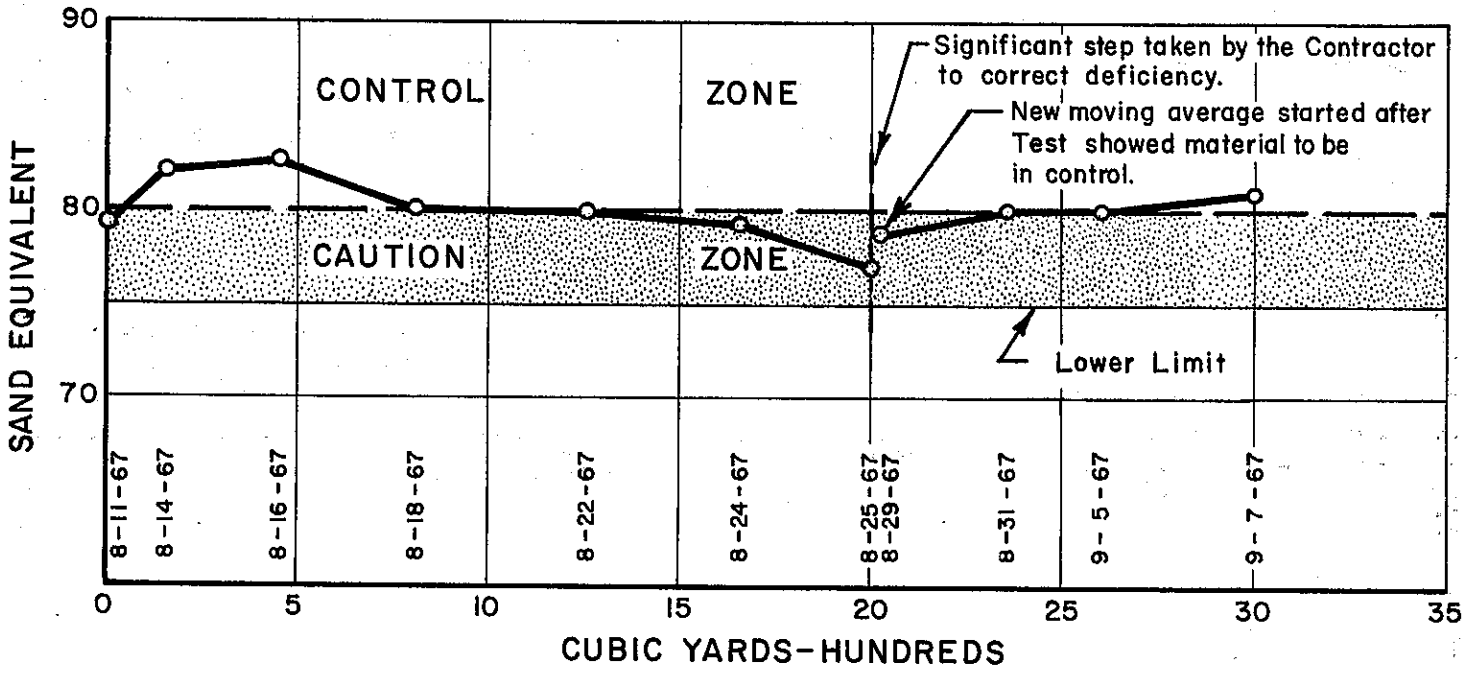
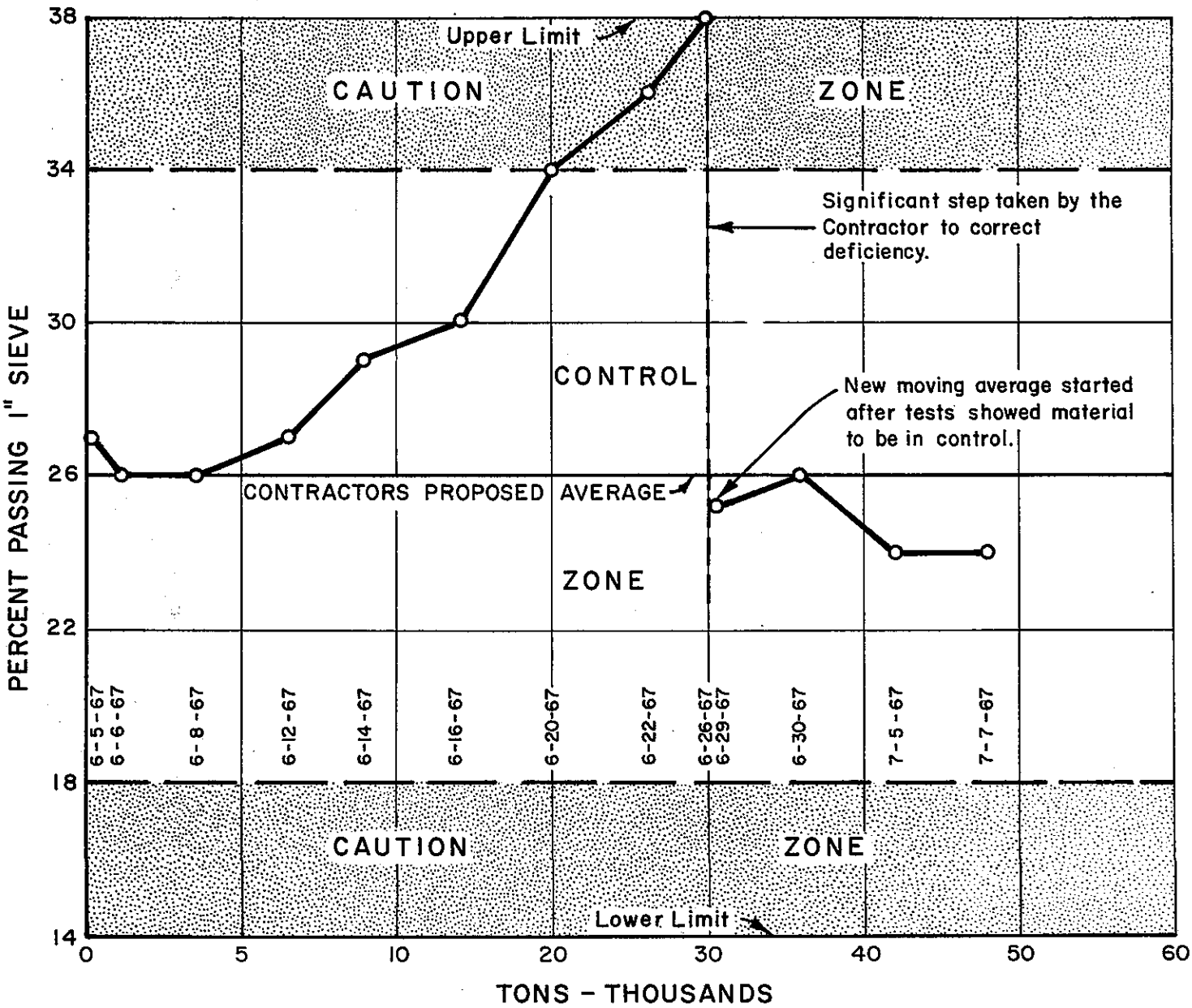


Figure II

CONTROL CHART OF MOVING AVERAGES FOR GRADING ANALYSIS



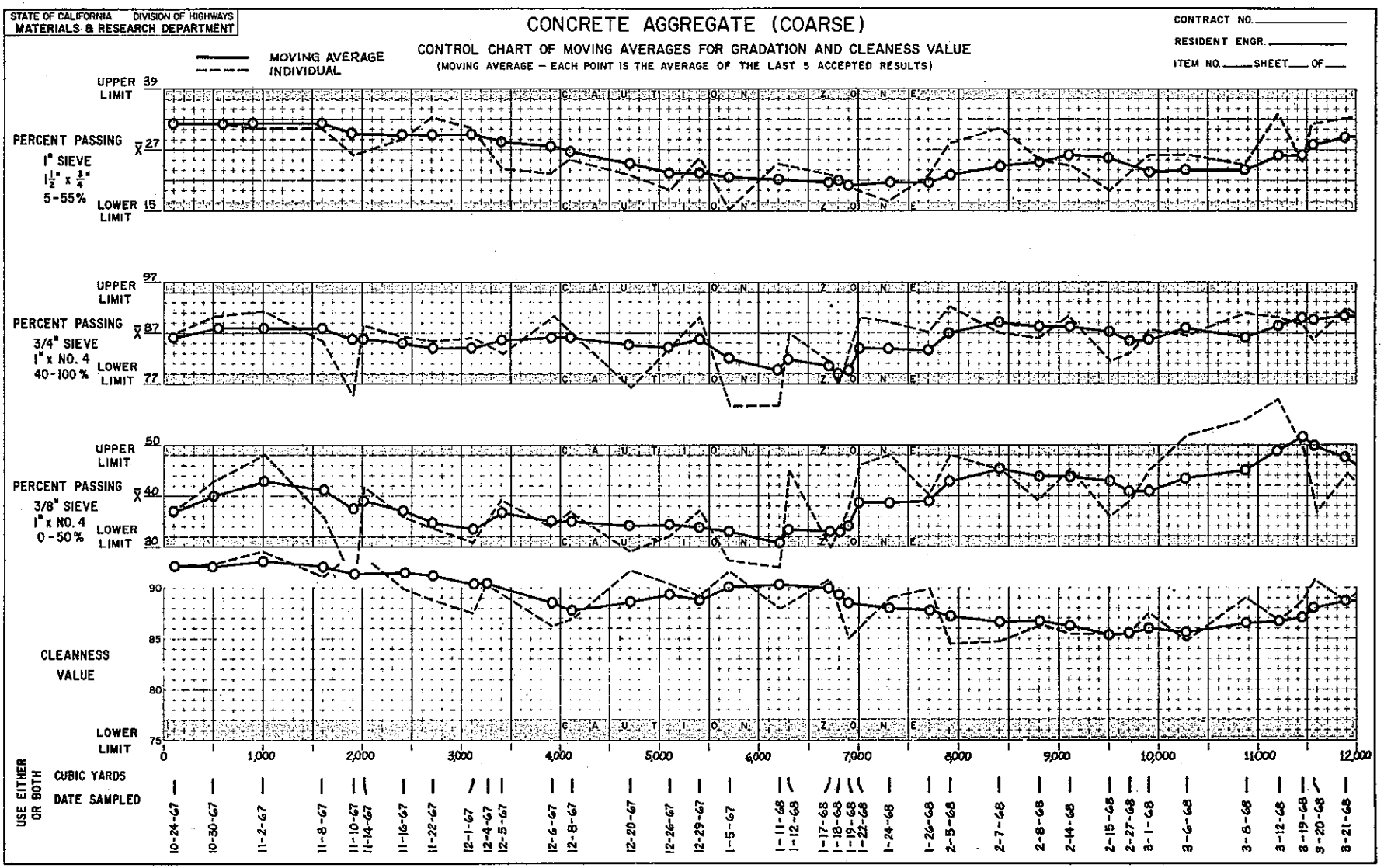
STATE OF CALIFORNIA DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

CONCRETE AGGREGATE (COARSE)

CONTRACT NO. _____
RESIDENT ENGR. _____
ITEM NO. ____ SHEET ____ OF ____

CONTROL CHART OF MOVING AVERAGES FOR GRADATION AND CLEANESS VALUE

(MOVING AVERAGE – EACH POINT IS THE AVERAGE OF THE LAST 5 ACCEPTED RESULTS)



STATE OF CALIFORNIA DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

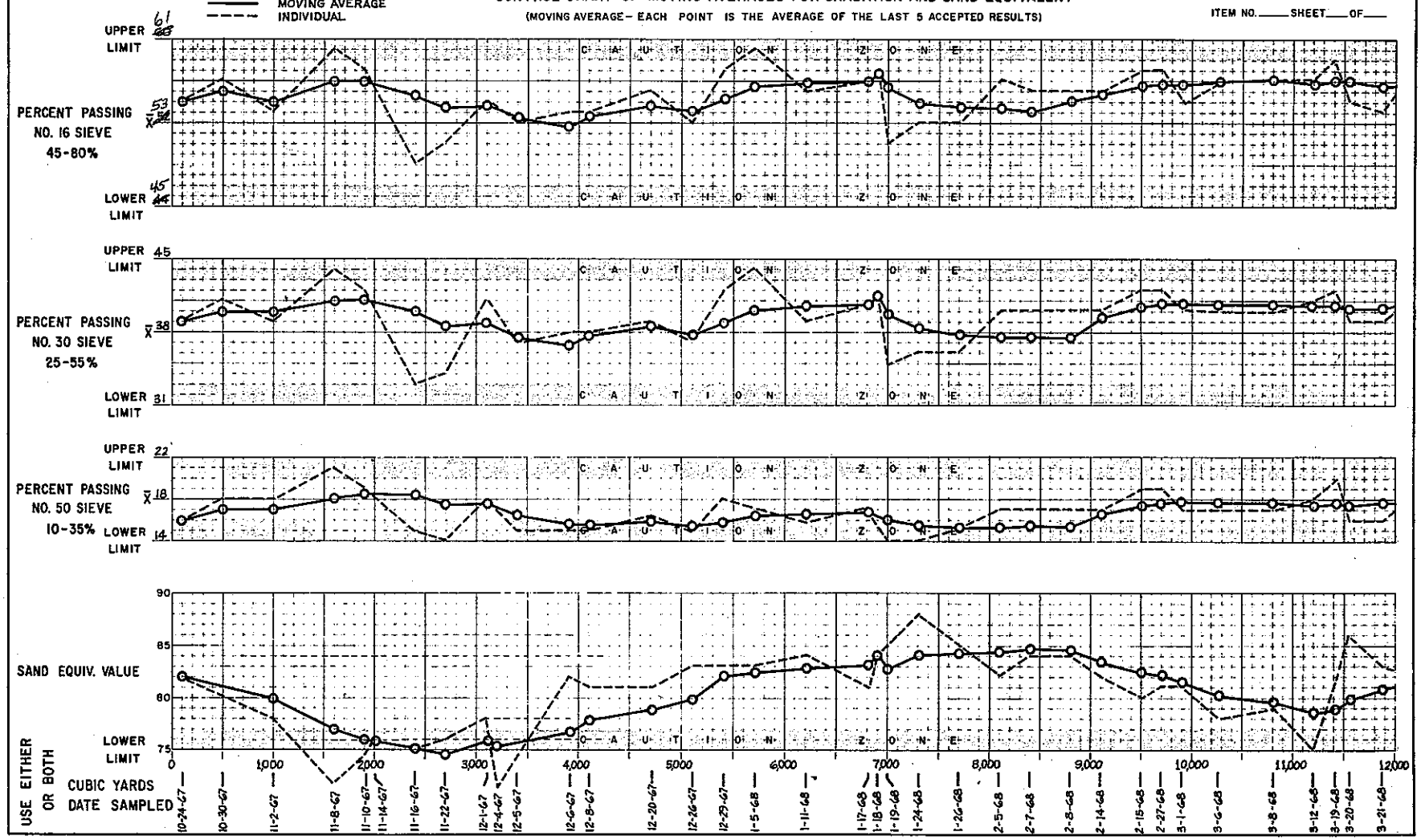
CONCRETE AGGREGATE (FINE)

CONTROL CHART OF MOVING AVERAGES FOR GRADATION AND SAND EQUIVALENT

(MOVING AVERAGE – EACH POINT IS THE AVERAGE OF THE LAST 5 ACCEPTED RESULTS)

CONTRACT NO. _____
RESIDENT ENGR. _____
ITEM NO. ____ SHEET ____ OF ____

MOVING AVERAGE
INDIVIDUAL



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